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SAFETY ASPECTS RELATED TO THE RADIOACTIVELY CONTAMINATED FOREST AREAS IN BELARUS*

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Safety Aspects Related to the Radioactively Contaminated Forest Areas in Belarus*

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ABSTRACT

Doses currently received in Belarus through various pathways related to the contamination of forests are evaluated through calculations. A major pathway is, as expected, generally found to be the external radiation from a contaminated forest floor. Also other pathways may in some cases be highly significant. Generally, it is found that the dose contributions to people spending time in the contaminated forest or consuming forest products are highest, whereas for instance doses received from domestic use of fire-wood are found to be negligible. Recommendations for storage of waste from combustion plants fired with radioactive forest material are also given, together with an estimate of the specific activity of the waste to be disposed of.

INTRODUCTION

This paper describes and roughly quantifies the exposure dose rates received by humans in Belarus from contamination in forested areas. The dose pathways were classified in nine different categories. These were:

1. External doses from contamination on ground
2. Internal doses from consumption of forest foods
3. External exposure from contamination on trees
4. Handling of forestry material
5. Inhalation doses from forestry work (sawing)
6. Direct dose contribution from domestic furnaces
7. Doses from application of radioactive ash for fertilizer
8. Doses from inhalation of aerosol released from domestic wood-fired furnaces
9. Doses received due to forest fires

The main task of this work was to quantify the doses that could occur in forested areas of Belarus. From assumptions of the local behavior pattern, which could easily be scaled up or down in order to reflect the conditions in a particular scenario, estimates were made of the typical doses that would be expected. The general approach followed through most of the studies was to first estimate the maximum expectable doses and based on this calculation

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together with a more realistic evaluation of critical parameters to find the level of doses that were likely to generally be observed over a population. These latter individual doses could then form the basis for an evaluation of collective doses in the contaminated forest areas of Belarus.

The dose contributions evaluated in this paper could all be reduced substantially by remedial action. If all vegetation and a 10 cm duff layer from the forest floor were removed, it would not only have a great dose reductive effect, an economic advantage could be obtained through using the removed biomaterial in a specially constructed combustion plant. This would also act to reduce the volume of contaminated material while placing the contamination under state control.

DOSE PATHWAYS TO BE CONSIDERED IN THE BASELINE STUDY

External Doses from ^{137}Cs Contamination on Ground

For this calculation the American consequence assessment model RESRAD (Yu et. al., 1993) was applied. Unless stated otherwise, default RESRAD parameters were used in the modeling.

A unit areal contamination level of 1 Ci/km^2 was assumed. This is approximately equal to 0.5 Bq/g (13.3 pCi/g) of soil, with the assumptions that the contamination is homogeneously distributed over the top 5 cm of the vertical soil profile and the soil density was modeled as 1.5 g/cm^3. This value reflects typical conditions for Belarussian soils, which have been found to vary from 0.7 to 1.8 g/cm^3 (Hubert et al., 1996). Due to the high content of organic material in the forest topsoil, the soil density is, however, here generally in the low end of the range. Evapotranspiration coefficients and irrigation parameters were lowered considerably compared to the defaults of RESRAD, in order to eliminate contamination depletion. Working exposure dose rates were calculated over a period of 70 years - with the stipulation that the workers do not spend any of the working time indoors, and that about 25 % of the total time is spent working outdoors. The sensitivity analysis parameter (by which input is scaled) is 2.

The RESRAD estimate of the annual doses received over time is shown in Figure 1. The peak dose occurred initially and was approximately 0.06 mSv/yr (6 mrem/yr). The sensitivity in dose towards changes in the thickness of the contaminated soil layer, assuming a constant contamination level of 0.5 Bq/g (13.3 pCi/g) throughout the entire contaminated layer has been evaluated and is presented in Figure 2. As can be seen, if a unit areal contamination is assumed rather than a unit volume contamination density, the curves for thicknesses 0.025 and 0.05 m differ by only some 10 %. The sensitivity in dose scales linearly with the changes in the fraction of time spent outdoors working.

The sensitivity analysis towards the size of the contaminated area shows a weak dependence on size for areas greater than 1000 m^2. The assumed fraction of time spent working outdoors was 0.1.

PLACE FIGURE 1 here

PLACE FIGURE 2 here

Table 1 below shows the calculated dose rates for continuous exposure to a 1 Ci/km^2 contamination homogeneously distributed over topsoil layers of different thickness. The results displayed in Table 1 are for RESRAD calculations and for a Monte Carlo model developed at RECOM Ltd. in Moscow.

Table 1. Comparison between the results of two different models for calculation of the dose rate from a homogeneous contribution from ^{137}Cs distributed through a topsoil layer of varying thickness. The contamination is for all distributions 1 Ci/km^2.

Top layer thickness in centimetres	D′ (RESRAD) mSv/yr	D′ (RECOM) mSv/yr
0.5	0.46	0.34
2.5	0.31	0.30
5	0.24	0.26
10	0.17	0.20
15	0.13	0.16
20	0.10	0.13
25	0.086	0.11
30	0.073	0.096
35	0.063	0.084
40	0.055	0.074

The data in the table demonstrate that the simple modeling approach used in RESRAD agrees reasonably well with the more detailed Monte Carlo photon transport analysis of RECOM.

Another way to calculate a dose from ground contamination is by application of dose response factors for infinite, homogeneous isotropic plane sources distributed at different depths in the ground. This was done by the Monte Carlo photon transport code MCNP, and simulations of the similar code SAM-CE (Table 2) verified the results. The soil density was here assumed to be almost the same - 1.625 g/cm^3. From this type of information, the dose contribution can be calculated in relation to the actual vertical contamination profile. For this purpose it is appropriate at this stage after the Chernobyl accident to assume some Lorenz distribution throughout the top 20-cm layer. A contamination level of 40 Ci/km^2 will according to Table 2 result in a dose rate of about 1.5 μSv/h, which is in good agreement with experimental results obtained by Risoe staff in the contaminated areas in the summer of 1996.

Table 2. Kerma rate factors (Gy/year per gamma/s cm^{-2}) for infinite, homogeneous isotropic plane sources of 661.6 keV (^{137}Cs) at different depths in the ground - results obtained by MCNP/SAM-CE.

Depth, cm	0.1	0.3	1.0	3.0	10.0	30.0
Kerma rate	$2.2\ 10^{-4}$	$1.8\ 10^{-4}$	$1.3\ 10^{-4}$	$8.0\ 10^{-5}$	$2.8\ 10^{-5}$	$2.5\ 10^{-6}$

Some guidance on the influence on dose rates of the size of open areas can be deduced from calculations made with the MCNP code, which have shown that with a normal initial distribution of a ^{137}Cs contamination, about 13 % of the dose rate in an infinitely large field can be ascribed to the contamination within a circular area of the soil with a radius of 1m. It was found that 34 % of the dose rate is due to the part of the contamination that is more than 16m away, and 13 % comes from contaminated areas more than 64m away (Andersson, 1996).

Table 3 shows the maximum working hours for forestry workers in contaminated zones according to Belarus legislation (Belarus Ministry of Emergency, 1995).

Table 3 Maximum permissible working hours for forestry workers (hours/year)

Exposure dose rate(EDR) on the working place, υR/hour	Exposure dose rate (EDR) on the working place, mSv/yr	For workers working on open territory	Machinery workers
70-150	6.1-13.1	1150	unlimited
150-200	13.1-17.5	760	1120
200-250	17.5-21.9	580	870
250-300	21.9-26.3	470	690
more than 300	more than 26.3	400	580

Calculations made at RECOM have shown that for the Belarussian forests, the shielding effect of the trees on the external dose rate due to the ground contamination is of approximately the same size as the extra contribution to the ground contamination dose rate from scattering of radiation up in the trees (Chesnokov et al, 1998).

Internal Doses from Consumption of Forest Foods

A rather high consumption rate of 10 kg of mushrooms per year was assumed in the following 'worst case' calculations to quantify this dose pathway. The maximum measured concentration of cesium (^{137}Cs) in mushrooms 1.5 10^7 Bq/kg (400 υCi/kg), (Parfenov and Yakushev, 1995) was assumed in the calculation. Using the ingestion dose coefficient from ICRP 72 (1995), the annual dose due to this intake of mushrooms with the maximum concentration was found to be of the order of 0.27 Sv. Although this is a very high dose, it must be stressed that average cesium concentrations in mushrooms are several orders of magnitude lower (Jacob and Likhtarov, 1996). Many contaminated mushroom species are consumed; however, the consumption rate for the high-concentration species is low.

Therefore, the average Cs content of the mushrooms that are consumed is expected to be several orders of magnitude lower than the maximum value (Hubert et al., 1996; Jacob and Likhtarov, 1996; IAEA, 1993). Cesium contents of 3200 Bq/kg (0.088 μCi/kg) have been reported for popular species, corresponding to annual doses of the order of 50 μSv per year. Therefore, it is important to concentrate on which mushroom species are consumed in large quantities. Some mushroom species in the contaminated areas contain practically no contamination at all (Parfenov and Yakushev, 1995). Also, the consumption rates vary much between different parts of the population. Only the people living in the rural districts close to forests would be expected to consume as much as 10 kg of mushrooms per year. People living in more remote rural districts consume some 1-5 kg in a year, while the majority of the population living in urban areas are reported to consume less than 100 grams in a year (Jacob and Likhtarov, 1996, Ipatiev, 1994). This means that the minimum doses received would be of the order of 0.5 μSv/year when 100 grams of mushrooms is the yearly consumption rate. Further treatment of mushrooms for food preparation, e.g. by frying, may reduce the contamination level.

Consumption doses for mushrooms were also estimated using RESRAD. All input parameters were assumed to be model defaults (Yu et al., 1993), except the soil concentration of cesium. Cesium concentrations in soil were changed so as to give the maximum measured concentration of cesium in mushrooms, i.e. 1.5 10^7 Bq/kg. The applied soil to plant transfer factor is 0.04. This transfer factor is a fixed value in the RESRAD model. The RESRAD model was run for the same sort of 'worst case' assumptions as stated above in connection with the ICRP 72 estimate. Here the model estimated the annual maximum dose to be almost 1 Sv, which is a factor of four than the analysis based on ICRP 72.

Concerning the consumption of berries the maximum contamination level has been reported to be 1.55 10^7 Bq/kg (420 μCi/kg), which corresponds roughly to that reported for the most contaminated mushrooms. However, the typical value of contamination is reported to be about two orders of magnitude lower than the typical value for mushrooms. Although an average as such is difficult to define, as there are many berry species and many different conditions of growth, it is certain that Cs concentrations will be substantially lower for berries than it will for mushrooms. Further, the reported consumption rates for berries are only approximately half of those reported for mushrooms (Jacob and Likhtarov, 1996; Ipatiev, 1994). This implies that, if the dose ingestion factors for berries and mushrooms were identical, doses received from berries would generally be of minor importance compared with that received from mushrooms.

The estimated dose that can be expected with the high consumption rate of 10 kg of mushrooms per year and the typical radiocesium content of 3230 Bq/kg (0.088 μCi/kg) has been calculated as 0.23 mSv/yr which is 23% of the maximum permissible annual dose. The dose rate is linearly proportional to the consumption rate.

For collective dose purposes an estimate had to be made of an average dose from intake of mushrooms from the forest.

It was calculated from Belarussian population numbers from January 1996 that about 65 % of the population lives in what is characterized as urban areas, while 35 % live in areas classified as rural. These values were applied together with averaged data for the mushroom consumption rates for urban and rural populations, to get an average consumption rate for the entire population (Hubert et al., 1996; Jacob and Likhtarov, 1996; IAEA, 1993). This was found to amount to 2.2 kg/year of mushrooms. This was applied as input to yet another run with the RESRAD, assuming a radiocesium content of 3230 Bq/kg. The results of this run are shown in Figure 3. The Figure shows not only the values for the above given averaged consumption rate, but also those for half and for twice that value. A multiplication of the dose rate for 2.2-kg mushrooms per year by the total population gives a collective dose of 80 manSv. Due to the much lower content of radioactivity in berries and also a somewhat lower consumption rate the collective dose for intake of berries was estimated to be about 1 manSv.

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External Exposure from Contamination on Trees

In this calculation, which was made with the code RESRAD Build, it was assumed that a person is located in the center of a 2m by 2m square, which has trees in each of the four corners. The more distant trees are estimated to account for half as much, as are the nearest 4, assuming a constant spacing of the trees in the forest. It was further estimated for the calculation that the person spends 25 % of the total time of a year in the forest area. The trees are assumed to have a diameter of 30 cm, a 'model default height' of 36 m, and a density of 800 kg/m^3, which are parameters that are thought to adequately reflect average conditions in Belarussian forests. In the calculation the highest referenced value of specific contamination was applied 1.5 10^6 Bq/kg (4 10^{-5} Ci/kg). This level of contamination is actually only reported for bark and is therefore an extremely high level of contamination for the whole wood mass of the trees. In comparison with this, the maximum permitted specific contamination of wood mass is 80 times lower, and by far the most of the wood in the contaminated forests can actually meet this limit. The specific level of radioactivity in the bark is normally some 15 times as high as that in the wood tissue. For pine trees, for instance, it has been found by the Akademia Nauk Belarus (Parfenov and Yakushev, 1995) that about half of the total amount of contamination in the whole tree is in the bark mass. Further, the RESRAD Build model does not take into account the self-attenuation of the trees.

Naturally, the applied geometry approach is very sensitive towards the actual distance between trees and the exposed individual. However, for a time-averaged calculation, it should be assumed that the person is most of the time not in physical contact with or very close to the trees. For the purpose of a maximum dose evaluation the assumption is made that the effect of closer 'contact' with trees together with the contribution from distant trees doubles the dose compared with that found in the calculation with the fixed-distance 4-tree scenario.

The result of the RESRAD Build model run was an external dose rate estimate of 93 mSv/year for the 4-tree geometry, and therefore for the whole forest it would amount to 186 mSv/year. This is an extremely conservative estimate due to the high concentration level that was assumed to occur in the entire tree.

A RESRAD Build calculation was also made assuming a distribution of the contamination (with the 1.5 10^6 Bq/kg level) only in a 1 cm thick layer of bark, since according to the measurement data the specific contamination level of the wood is much lower. This much more realistic calculation gave a dose rate of only about 2 mSv/year compared with the 186 mSv/year found above. This value for the external dose from the trees is comparable with the external dose from a ground contamination level of 40 Ci/km^2, which is 3 mSv/yr.
The sensitivity of the dose to the tree height was estimated. For trees with a height of 24 m, the RESRAD Build dose rate estimate is only about 2 % less than that with the 36-m high trees.

Handling of Forestry Material

The general approach followed in the calculations for this pathway differs only slightly from the above. It was here assumed in the RESRAD Build calculations that the persons handling the forestry material (e.g. sawing) are much closer to the contaminated trees than are the people who are just present in the forest (for mushroom collection, recreational activities, etc.). Here the distance to one of the contaminated trees is assumed to be only 30 cm. The fraction of time spent in the forest was here again assumed to be 25 %. The dose rate corresponding to a 1 cm layer of bark contaminated with 1.5 10^6 Bq/kg (4 10^{-5} Ci/kg) would here amount to 2.8 mSv/year, taking into account the contribution from the forest as a whole.

Inhalation Doses from Forestry Work (sawing)

This dose pathway is assumed to be negligible partly because of the comparatively low level of radioactivity in the wood and partly due to the fact that the saw dust particles are large and will soon settle and thus not constitute an inhalation hazard. An estimate was made of the total mass of sawdust created by cutting a 30-cm diameter tree, assuming that the width of the saw blade is 1 cm. This mass was here found to be 0.5 kg. Any saw dust consisting of sufficiently small particles to form an inhalation hazard would have very little mass and proportionally little contamination. Even if it is assumed that 0.5 milligrammes per tree were actually of an inhalable size, it follows from the ICRP 72 inhalation dose coefficients (value for slow absorption was applied for conservative purposes) that the dose received from cutting one tree would amount to only about 0.4 nSv, assuming that the wood has a specific concentration of 1.85 10^4 Bq/kg (5 10^{-7} Ci/kg) (maximum permitted level for wood (Belarus Ministry of Emergency, 1995). From the assumption that the sawing procedure is carried out once every minute in a working year it follows that 120000 trunks could be cut in a year. This would give a dose of 48 μSv in a year - corresponding to an annual inhalation of 60 grammes, which is an extremely high mass load.

Direct Dose Contribution from Domestic Furnaces

In the calculations which were performed using RESRAD Build it was assumed that the furnace type of primary concern is the Russian bed type, since there is practically one in each home and it is used by one of the inhabitants of the house to sleep on. Thereby, the distance between the source (radioactive firewood and ash) and the person is very short, and the doses correspondingly large. It is assumed that with this furnace design there is an 8-cm layer of brick between the firewood and the person sleeping (8 hours per night) on top of the furnace. The furnace is assumed to constantly be half full (on average) of firewood and the ash container, which is located below the furnace is assumed to also be half full, on average. The ash container is typically emptied once a week. Therefore, on average it contains 7/2 = 3.5 times as much contamination as does the furnace container. However, the distance between the person and the ash container is assumed to be twice that between the person and the furnace container. This means that the dose rate contribution from the ash container should be 3.5/4 times (roughly: 1) as high as that from the furnace firewood container. The furnace is in use over a six-month period from October to March (IPEP, 1998).

The calculations were made from the assumption that the contamination content of the firewood is the maximum permissible level for firewood, 740 Bq/kg, ($2\ 10^{-8}$ Ci/kg). From reported amounts of wood used in the furnaces over a year, it follows that the amount of firewood applied per day is on average 40 kg (IPEP, 1998). This wood would contain $3\ 10^{4}$ Bq of contamination. In the model, it was assumed that this contamination was located in a firewood container equivalent position at a distance of 30 cm from the person sleeping on top of the furnace. The calculation with RESRAD Build gave a corresponding dose rate of 0.02 mSv/year. Multiplied by 2, to take into account the contribution from the ash container, this gives 0.04 mSv/year.

Collective dose rates were calculated for the rural population of the Gomel area, which is close to contaminated forests and apply this type of furnace. It is assumed in these calculations that there are 3 persons in each home with a furnace, and that only one of these can sleep on top of the furnace and get this type of doses. The population of these areas has been reported to be 318813 persons, and the collective dose contribution to this population would therefore be 4.3 Sv.

Doses from Application of Radioactive Ash for Fertilizer

The common practice in Belarus to deal with the radioactive ash for use as fertilizer is to dig a hole in the back yard into which the ash container is emptied. The ash is then mixed with the soil substances, the fertilizer is diluted and the moisture content rises, before the ash-mixture is dug up (usually about 1 year later) and applied as fertilizer in fields. At this stage the inhalation risk is believed to be negligible.

A rough estimate was made of the extra soil contamination that would occur by application of the fertilizer to the land areas. Roughly 600,000 tons of wood is burned in a year in the Gomel and Mogilev provinces (IPEP, 1995), which cover most of the highly contaminated areas. If it is assumed that the contamination content is 730 Bq/kg (2 10^{-8} Ci/kg) this amounts to a total of 4.4 10^{11} Bq. (12 Ci), which is spread over an area of 14667 km^2, giving an extra soil contamination of about 8 10^{-4} Ci/km^2. In comparison with this, levels exceeding 2 Ci/km^2 already contaminate almost 40% of the land.

A screening level RESRAD estimate of extra consumption dose from application of this fertilizer over the fields gives 2 Sv/year collectively over a population of 0.5 million.

Doses from Inhalation of Aerosol Released from Domestic Wood-Fired Furnaces

A COSYMA run was made for the estimation. Here it was estimated that the particle size of the contaminants is about 10 microns. Prevailing weather conditions were assumed and further the assumption was made that there was no rain and a 'unit release' of 10^{18} Bq came out of a 5-m high chimney. Figure 4 shows the time-integrated air-concentrations of the cesium aerosol as a function of distance. As can be seen, the concentration decreases very steeply (by several orders of magnitude over a few 100m). As there is assumed to be several 100 m between chimneys, only the releases from one chimney can ever be registered. As can be seen from the Figure, a unit release of 1 Bq would lead to a time-integrated air concentration of 10^{-4} Bq s/m^3 on average over the closest few hundred meters. By multiplication with the default breathing rate applied in COSYMA (2.67 10^{-4} m^3/s) this gives a total amount of inhaled matter of 2.67 10^{-8} per Bq released. In reality, the firewood for one household contains 5.5 MBq (corresponding to the highest permittable level of contamination in firewood) applied in a year. If it is assumed that 20 % of this gets released through the chimney, which would certainly be conservative, this is 1 MBq/year. The amount of inhaled matter from this size of release is thus 2.67 10^{-2} Bq/year. If this figure is multiplied by the highest Cs-137 inhalation dose coefficient from ICRP 72 (for slow absorption: 3.9 10^{-8} Sv/Bq), it follows that the dose received is in the order of 10^{-9} Sv/year. Even if some of the values assumed in this rough calculation were off by an order of magnitude, it can be concluded that the doses received through this pathway would be of a minor importance compared with those received from other pathways.

PLACE Figure 4 here

Doses Received Due to Forest Fires

For this dose pathway published material (Azarov, 1996) exists. The approach in this article was the following. The fire process was described in terms of the likely amount of ^{137}Cs released from a 25 ha fire in an area with a contamination level of 1.48 MBq/m^2 (40 Ci/km^2), with an air temperature of 25 C, atmospheric class C and wind velocity 5 m/s. From experimental data, Azarov found that the mass-average particle size of the aerosol released by the forest fires is of the order of 8 microns, while the number average of the aerosol size is 4-5 microns. Azarov applied this in the calculations of ^{137}Cs near-ground level air concentrations. These estimates were made for two different types of forest fires: a) a bottom fire, by which it is assumed that all the wood mass and a litter layer is burned, and b) an upper fire, which spreads from tree-top to tree-top and rarely has much effect on the bio-material in the bottom part of the forest. From this, the maximum time-integrated doses that would be received in the wind direction at different distances were calculated. These doses are shown in Table 4.

Table 4. Maximum doses at different distances from a forest fire in which 1.48 MBq/m^2 of ^{137}Cs was released (Azarov, 1996).

Distance, m	250	500	750	1000	1250	1500
Dose, Sv	2.13	1.34	0.45	0.21	0.04	0.008

According to this data, doses received in the wind direction and over shorter distances may be very large. Actually, even higher doses have been reported (V.G. Molodych, 1993). However, it is important to stress that the actual doses received in reality would be expected to be substantially smaller, since the reference assumes that the person is in the direct wind direction all the time. Also, by this approach the total ^{137}Cs release from a forest fire in an area of 25 ha was assumed to be released in one point. This would inevitably lead to a huge over-estimation of the doses, as deposition by sedimentation of these rather large particles would greatly deplete the plume. Further, it is very important to consider that over the period from 1991 to 1994 there were 22 large or medium sized forest fires with a total area of 3,900 ha. In comparison, the total of the area in which the fires occurred (the controlled contaminated area) is 6,700,000 ha. Since a fire would only affect a small area, due to e.g. the large aerosol size, the probability of having this type of exposure in a particular place is extremely little.

DISCUSSION / CONCLUSIONS

From the calculations it was possible to get an overview of the relative importance of the different dose pathways, seen from a collective dose perspective.

It can be concluded that the external dose contribution from ground contamination would always be highly significant, whether a person stays in a forested area or in an open field.

The internal individual dose contribution from consumption of forest foods could be high or low, depending on the actual contamination level and consumption rate, the latter of which varies greatly. Since the average consumption rate of these food products over large areas is rather high (the products are not only consumed by the locals), a calculation estimate with high, but not unrealistic input values, showed that the collective doses may well be significant.

Although the external exposure from contamination on trees will be significant, it is in all cases expected to be less than that from the ground contamination. Handling of forestry material may give an additional external dose contribution (to that received by just staying in the forest) to workers which is not insignificant, but which from a collective dose point of view would not have much importance.

The inhalation doses from forestry work were found to be without importance.

Likewise, the direct doses from domestic furnaces were found to be low, even if the furnace is fired with wood containing the maximum permittable radioactivity level.

Due to the generally followed application procedure of radioactive ash for fertilizing, the inhalation doses from this application are believed to be negligible. After the contaminated ash is applied for fertilizing a field, the additional amount of contamination will be negligible compared with what is already in the field. It is possible that the plant uptake of radioactive matter may be much more influenced by the fertilizing effect.

Doses received from inhalation of aerosol released from the domestic wood-fired furnaces were estimated to be negligible.

The doses received from a forest fire would only affect people over very short distances. A published reference gives the results of a calculation of these doses. Although the doses received over a short distance were here found to be high, they were probably highly over-estimated, due to simplifications in the modeling approach. Further, the probability of a fire affecting a particular area was found to be extremely low.

An overall conclusion of this work is that many of the evaluated dose pathways, which relate to the people who spend time in the forest or consume forest products, may give significant population doses, whereas the dose pathways from domestic use of contaminated wood for fire are believed to be insignificant. Doses received due to forest fires would, with the current fire frequency not give significant collective doses, although significant individual doses may occur and have been reported for fire-fighting personnel.

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Figure 1 External dose from ground contaminated with 1 Ci/km^2 of Cs-137 received by forestry workers, assuming they spend 25 % of the time on site. (1 mSv=100 mrem).

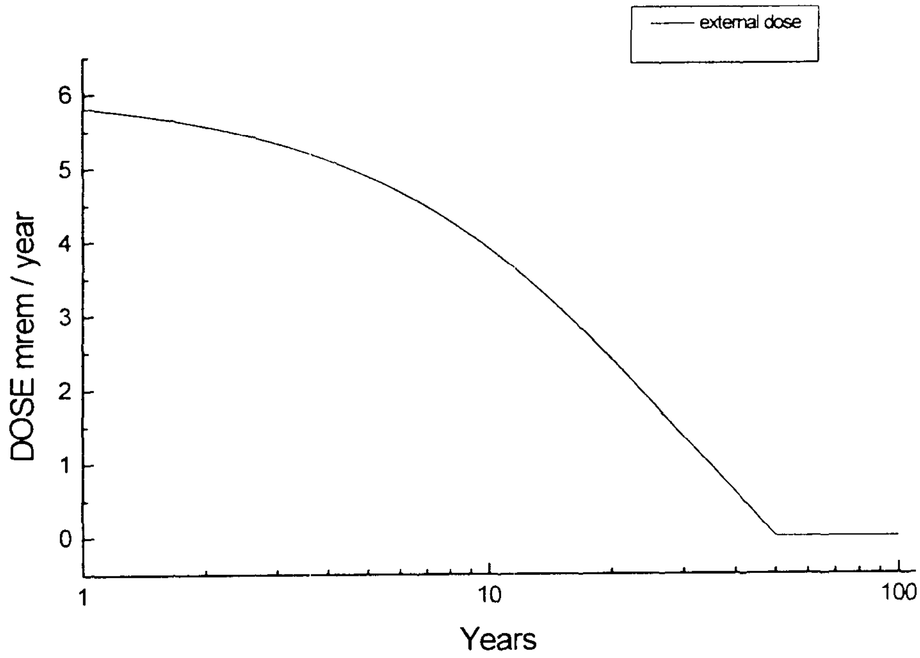

Figure 2 Sensitivity analysis towards the thickness of contaminated zone, Cs-137 content: 1 Ci/km^2 (1 mSv=100 mrem).

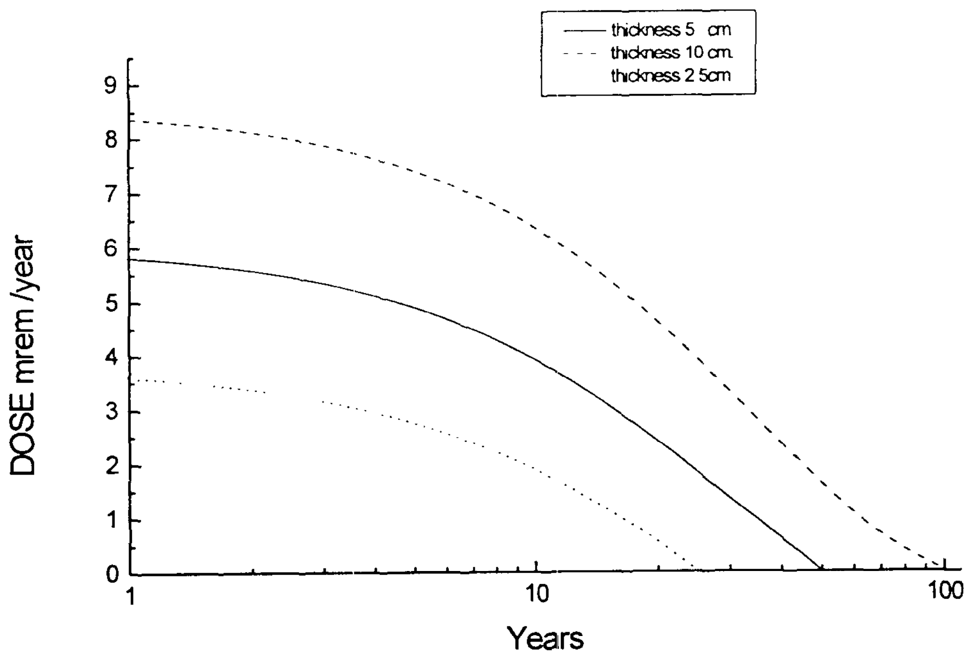

Figure 3 Sensitivity analysis towards the consumption rate of mushrooms. Cs-137 content - 0.088 micro Ci/kg (1 mSv=100 mrem).

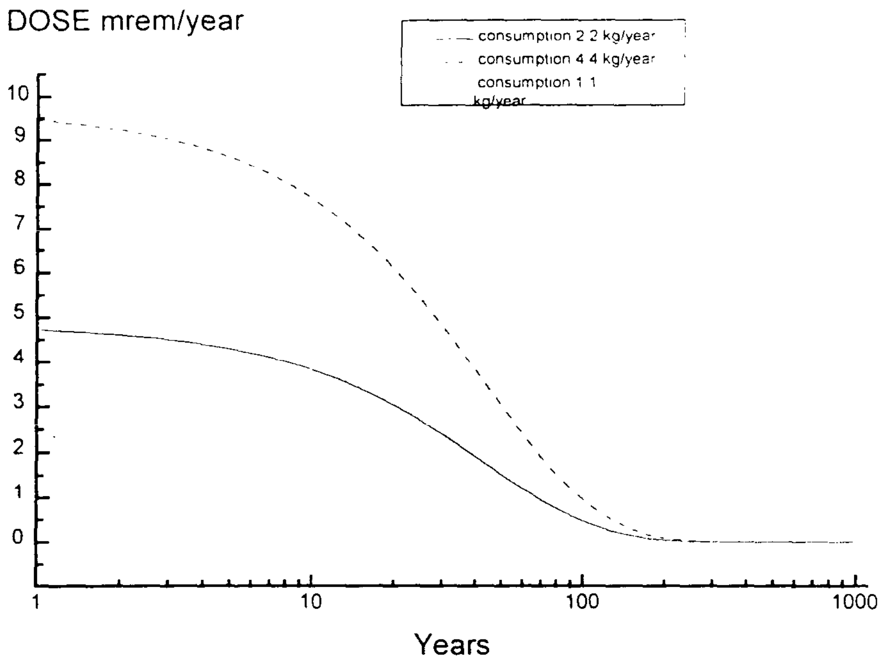

Figure 4 Concentration of Cs-137 in air as a distance from the chimney.